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Miscellaneous Paper HL-94-6
September 1994

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Flood Control Channels Research Program

San Timoteo Creek, California, Sedimentation Study

Numerical Model Investigation of In-Channel Sediment Basins

by Scott E. Stonestreet, Los Angeles District

20030305161

94-31539

Prepared for Headquarters, U.S. Army Corps of Engineers

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Numerical Model Investigation of In-Channel Sediment Basins

by Scott E. Stonestreet

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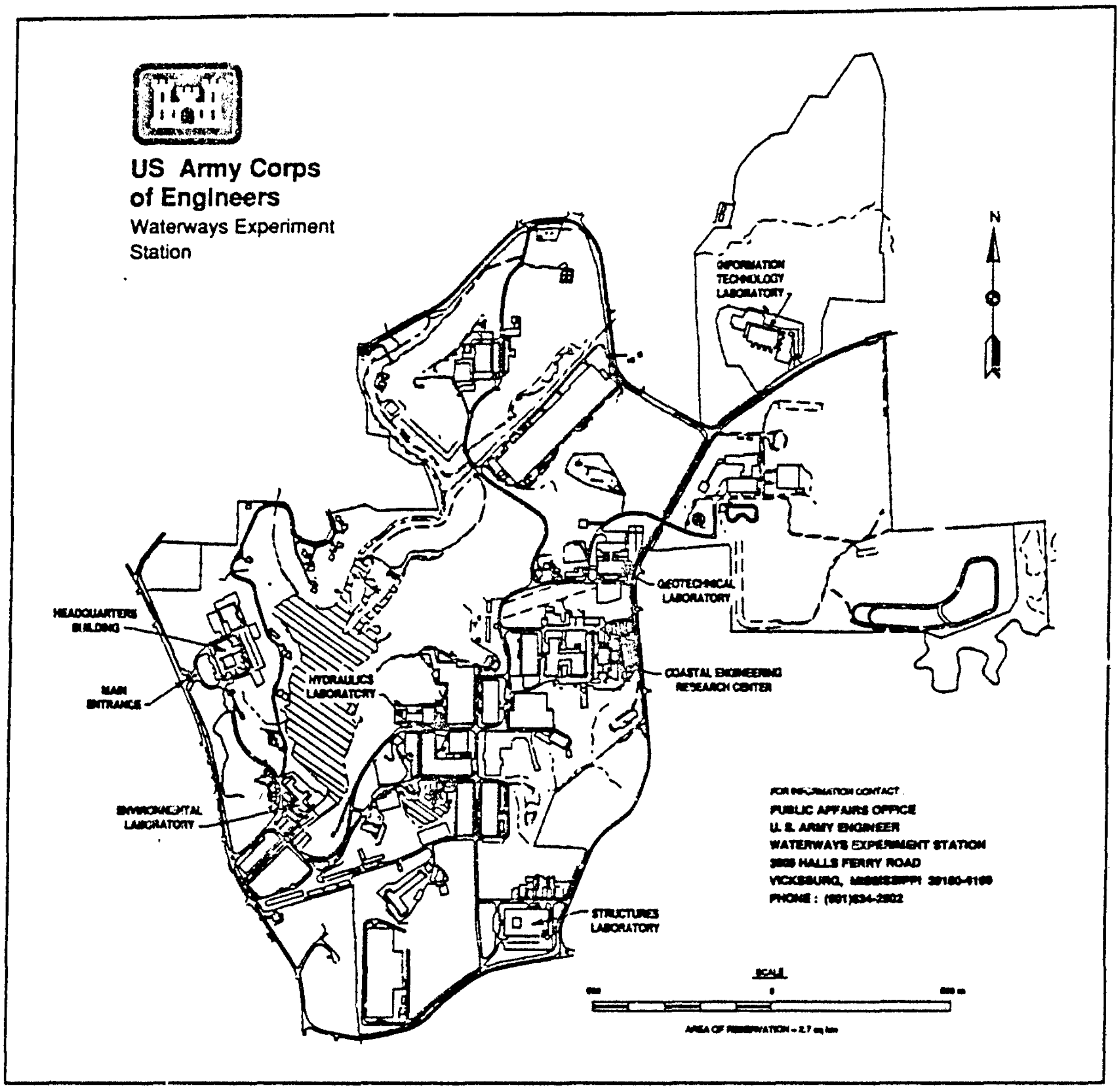
Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under Work Unit 32825

Monitored by U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199



Waterways Experiment Station Cataloging-in-Publication Data

Stonestreet, Scott E.
San Timoteo Creek, California, sedimentation study : numerical model investigation of in-channel sediment basins / by Scott E. Stonestreet ; prepared for U.S. Army Corps of Engineers ; monitored by U.S. Army Engineer Waterways Experiment Station.
36 p. : ill. ; 28 cm. -- (Miscellaneous paper ; HL-94-6)
Includes bibliographic references.
1. Settling basins -- Design and construction -- Data processing. 2. Sediment control -- California -- San Timoteo Creek. 3. Flood control -- California -- San Bernardino County. 4. Hydraulic structures -- Design and construction -- Mathematical models. I. United States. Army. Corps of Engineers. II. U.S. Army Engineer Waterways Experiment Station. III. Hydraulics Laboratory (U.S.) IV. Title. V. Title: Numerical model investigation of in-channel sediment basins. VI. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; HL-94-6.
TA7 W34m no.HL-94-6

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Preface

The investigation reported herein was conducted by the U.S. Army Engineer District, Los Angeles (SPL), during the period April 1990-June 1992 with general guidance and assistance provided by Dr. R. R. Copeland of the U.S. Army Engineer Waterways Experiment Station (WES). It documents the study of proposed channel improvements to the San Timoteo Creek, San Bernardino County, California. Specifically, the study examined the behavior of six in-channel debris basins. This report is being published as part of the Flood Control Channels Research Program, Work Unit 32825, "Sedimentation Basin Design," sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE). HQUSACE Technical Monitor for the Flood Control Channels Research Program was Mr. Thomas Munsey. This study provides a unique methodology for sediment basin design, and was identified during the research state-of-the-art literature review.

This study was conducted under the general supervision of Messrs. Robert Koplin, Chief of the Engineering Division, SPL; Joseph B. Evelyn, Chief of the Hydraulics and Hydrology Branch, SPL; and Brian G. Tracy, SPL, Chief of the Hydraulics Section, with Mr. Scott E. Stonestreet and Ms. Wendy S. Gist as project engineers, SPL. The report was written by Mr. Stonestreet. WES involvement in this study was under the general supervision of Messrs. F A. Herrmann, Jr., Director of the Hydraulics Laboratory, WES; R. A. Sager, Assistant Director of the Hydraulics Laboratory; and M. J. Trawle, Chief of the Mathematical Modelling Branch, Waterways Division, Hydraulics Laboratory; and under the direct supervision of Dr. R. R. Copeland, Research Hydraulic Engineer, Waterways Division, who also reviewed this report.

At the time of publication of this report, the District Engineer, SPL, was COL Robert L. VanAntwerp. Director of WES was Dr. Robert W. Whalin. Commander of WES was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acre-feet	1,233.482	cubic meters
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. statute)	1.609344	kilometers
square miles	2.589988	square kilometers

1 Introduction

General

The US Army Engineer District, Los Angeles (USAEDLA), has proposed to improve a portion of San Timoteo Creek located in San Bernardino County, California (USAEDLA 1990). The proposed channel improvement will convey the 100-year flood of 19,000 cfs[1] with a concrete, supercritical flood control channel. The San Timoteo Creek watershed has the potential to supply a large amount of sediment during a storm event due to sparse vegetation, steep slopes, and easily eroded soils. Therefore, to assure that the proposed channel will function as designed, a debris basin is required.

Description of Study Area

The San Timoteo Creek watershed at its confluence with the Santa Ana River comprises about 126 square miles and is located southeast of the City of San Bernardino, California, in Riverside and San Bernardino counties. The creek is formed by Yucaipa, Wilson, and Noble Creeks which have a combined drainage area of about 119 square miles. The study area is shown in Figure 1.

The proposed improvement includes the lower 5.2 miles of the creek as it flows from the foothills across an alluvial plain to the Santa Ana River. Upstream from the proposed channel improvements the bed is composed primarily of coarse sand with some gravel. The channel width varies due to extensive bank erosion, generally ranging in width between 100 ft and 300 ft. Average bed slopes through San Timoteo canyon range from 0.0131 ft/ft (69 ft/mile) near the proposed in-channel basins to 0.0145 ft/ft (77 ft/mile) in the sediment supply reach. The overall thalweg profile, in the study area, of San Timoteo and Yucaipa Creek is shown in Figure 2.

[1] A table of factors for converting non-SI units of measurement to SI (metric) units is found on page vi.

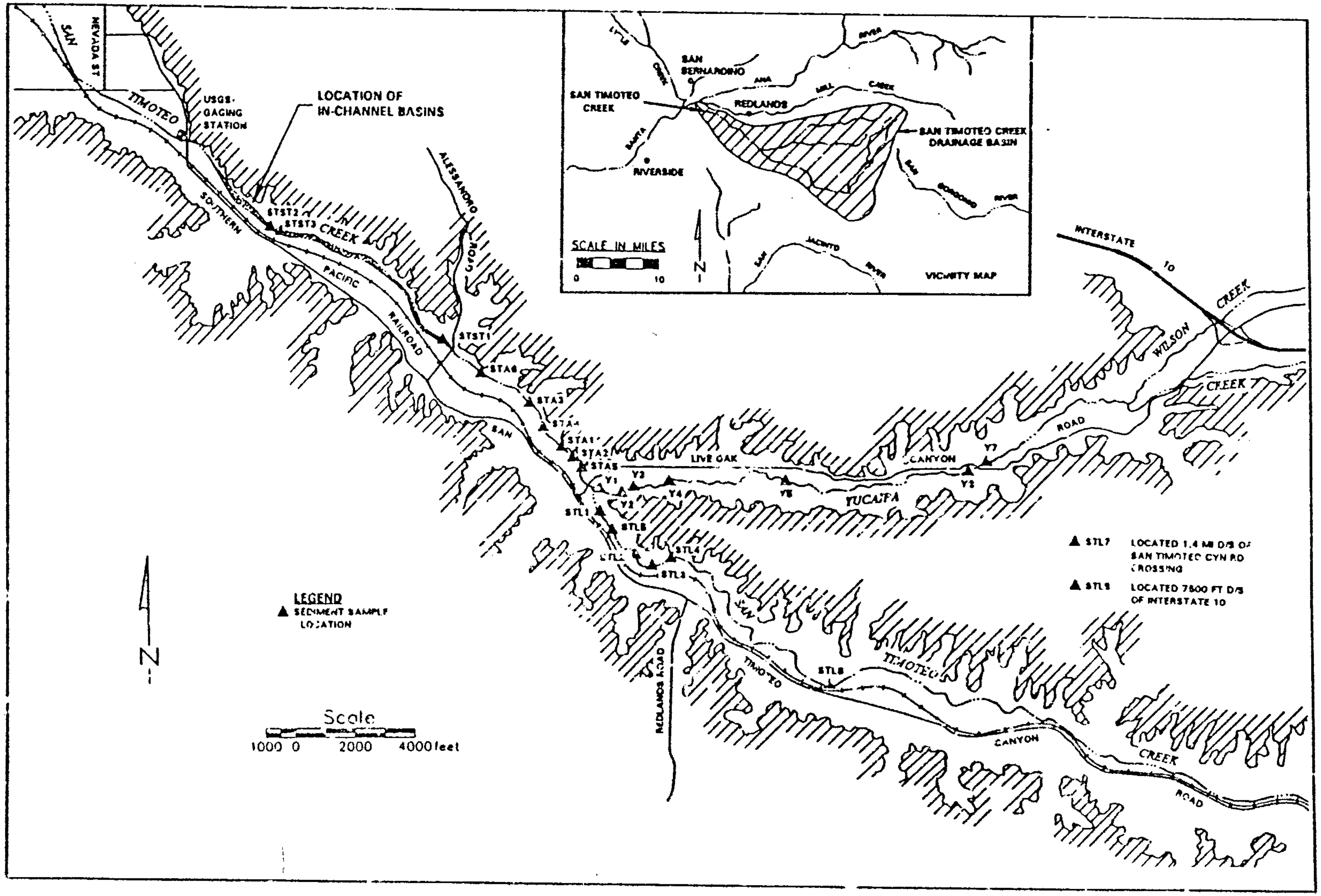


Figure 1. Study area and sediment sample locations

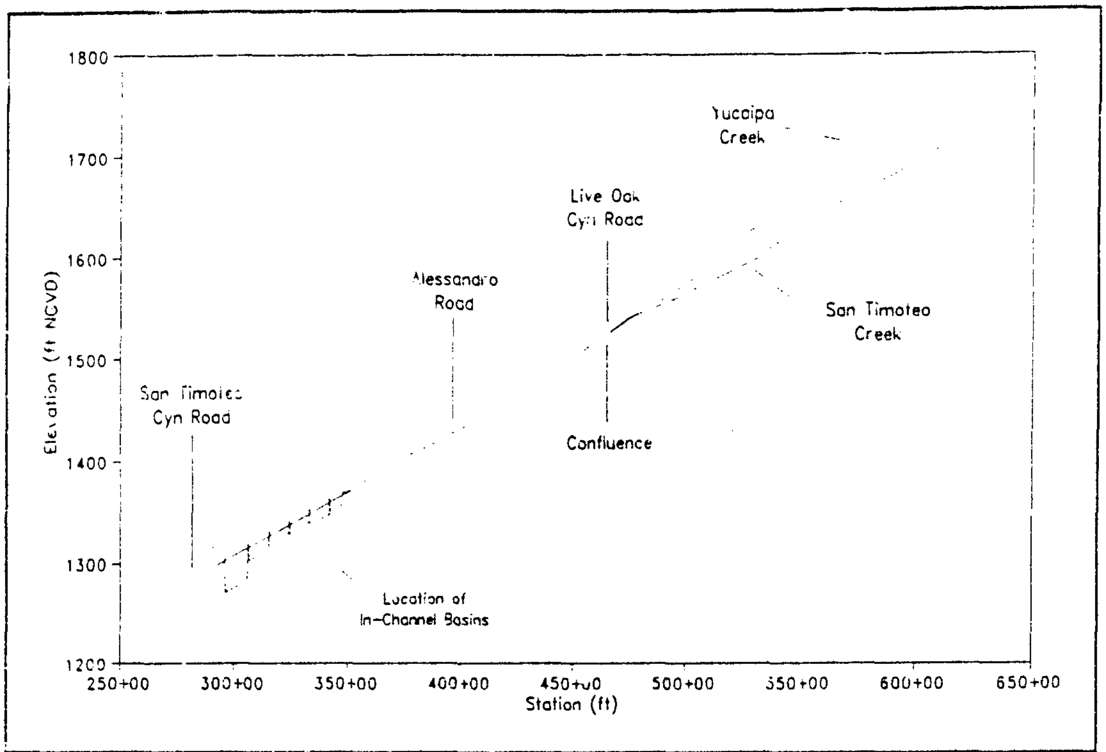


Figure 2. Thalweg profile of San Timoteo and Yucaipa Creeks

Debris Yield

An analysis was made to estimate the volume of debris delivered to the upstream end of the proposed project from the watershed. The debris yield was determined using the methods outlined in USAEDLA (1989). This method uses predictive regression equations which are based on watershed parameters and the combined probability of wildfire and flood. This analysis indicated that the single-event, 100-year frequency debris estimate is 700 acre-ft. Preliminary sediment transport analyses indicated potential problems with the channel inlet and outlet due to this large volume of debris.

Traditional Debris Basin Alternative

Initially, a traditional dam-style debris basin was designed to control debris and limit sediment inflow to the supercritical channel. However, due to the narrow canyon and further confinement by a railroad alignment, this structure had an embankment that had a maximum height of 68 ft above the channel invert and was over 2 miles long. The spillway, designed to meet Corps probable maximum flood (PMF) criteria for dams, resulted in a 400-ft-wide spillway with a crest approximately 43 ft above the channel invert.

The local residents and flood control agency found this design unacceptable aesthetically and raised many concerns about dam safety. Thus, an alternative solution to the dam-style debris basin was sought.

In-Channel Sediment Basin Alternative

In-channel sediment basins were designed as the alternative. As shown in Figure 3, the in-channel alternative consists of a total of six sediment basins in series. Five basins are excavated 11 ft below the channel invert and one basin is excavated 30 ft below the invert. Grouted stone stabilizers are located between the basins and rise to a height of 6 ft above the existing channel invert. The in-channel basins range in width from 300 to 550 ft and in length from 500 to 1100 ft. The alignment of the basins generally follows that of the creek bed.

The proposed in-channel sediment basins for this project were designed to function basically the same as a larger, dam-style, single debris basin. With a single debris basin, sediment-laden flows are detained with a combination of above-grade embankment and below-grade excavation. The flow detention causes significant reduction in velocity, greatly reducing the sediment transport capacity of the flow and inducing deposition of most of the bed-material load. Only the wash load and a relatively minor amount of bed-material load are passed over the spillway of the debris basin.

The main difference from the concept involving a single debris basin is that instead of a combination of below-grade excavation and a substantially above-grade embankment, these in-channel debris basins are above and below grade. The height of the stabilizer at the downstream end of each basin was limited to 6 ft above the existing channel invert to keep it below the classification of a dam.

The system of in-channel sediment basins will significantly reduce the inflow velocities. At the design discharge for the existing natural channel above the project inlet, calculated flow velocities from an HEC-2 backwater model ranged from 12 to 18 fps, while the calculated velocities within the basins ranged from 3 to 8 fps. The design length of the basins will result in a typical detention time of 4 minutes, which is sufficient time to settle out even the finest classification of sand.

The uppermost basin (basin 6 in Figure 3) will provide the initial trapping of sediment during the beginning of the design flood. As the basin fills up to the crest of the stabilizer, a condition of relative equilibrium will be attained between the rate of sediment inflow to the basin and the sediment transport capacity of the detained flow within the basin. Once the sediment storage capacity of the basin has been exceeded, all additional sediment inflow will be transported to the next downstream basin. The process will be repeated sequentially through each of the basins. The series of basins is designed to

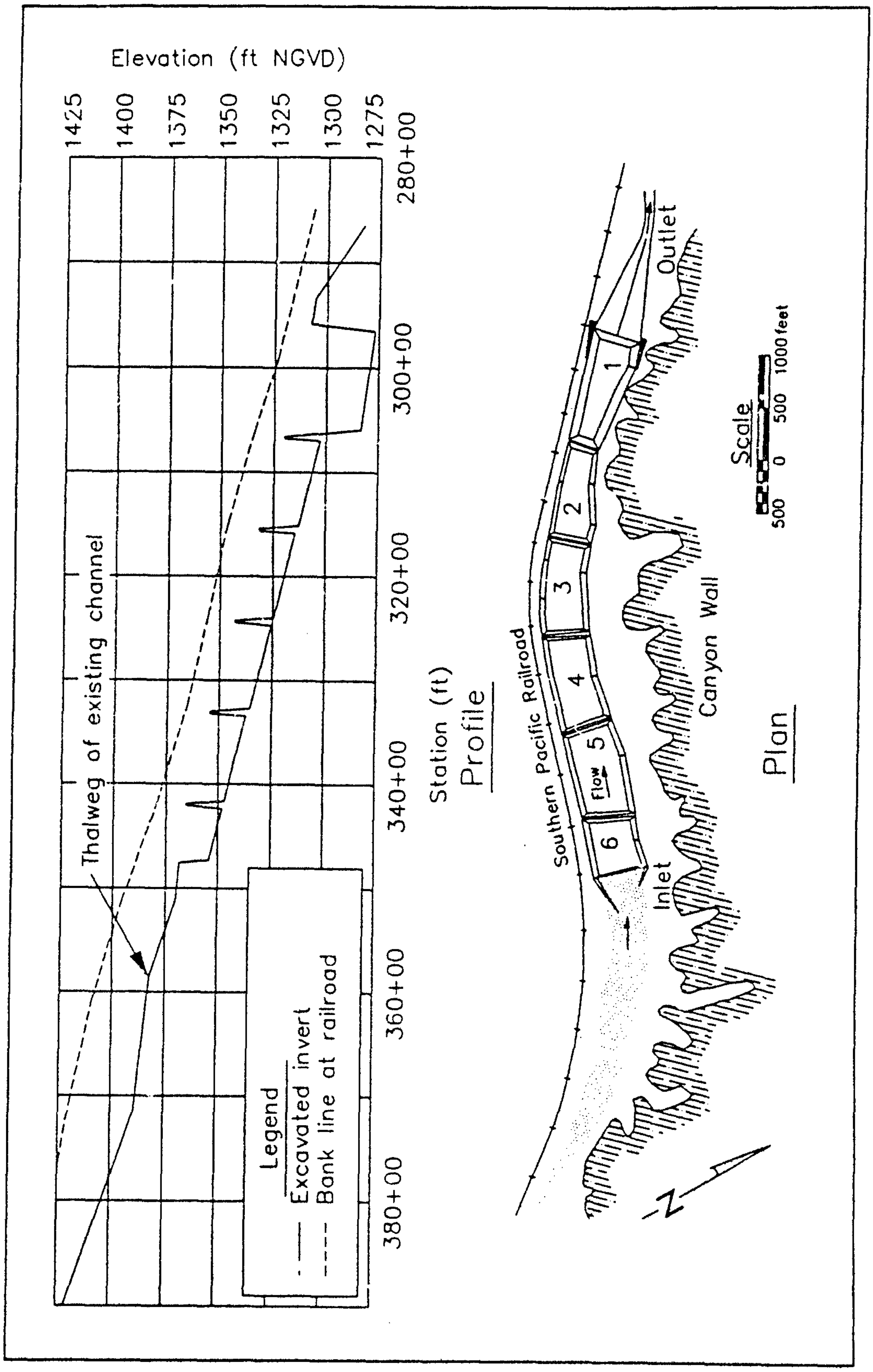


Figure 3. Plan and profile of in-channel basins

provide a total sediment storage capacity equal to the entire volume of sediment expected during the design flood, plus an allowance for sediment from antecedent flows.

Because San Timoteo Creek is well entrenched in the canyon bottom, levees or other flow containment structures are not needed to line the basins. In most cases, the stabilizer crests between basins are still well below the banks of the channel. A small berm will be required along the downstream end of basin 1 (see Figure 3) to make sure the flows enter the basin outlet structure.

Although the concept of utilizing several small sediment basins in series may seem rather unorthodox at first, it actually constitutes only relatively minor variations of the same proven concept used in the USAEDLA for many years to exclude large amounts of bed-material-sized sediment and debris from downstream channel improvements.

Purpose of Numerical Model Study

The purpose of this numerical model study was to determine the viability of the proposed in-channel sediment basins discussed above. Since the conceptual design of the basins was unproven and did not exist elsewhere, it was felt that a detailed analysis was required to verify the design. The analysis was conducted by the USAEDLA and reviewed by the Waterways Experiment Station (WES).

2 The Model

Description

A research version of the TABS-1 (HEC-6) one-dimensional sedimentation program was used to develop the numerical model for this study. The program produces a one-dimensional model that simulates the response of the riverbed profile to sediment inflow, bed material gradation, and hydraulic parameters. The model simulates a series of steady-state discharge events and their effects on the sediment transport capacity at cross sections and the resulting degradation or aggradation. The program calculates hydraulic parameters using a standard-step backwater method assuming subcritical flow. The program assigns critical depth for water surface elevation if the backwater calculations indicate transitions to supercritical flow. However, for supercritical flow, hydraulic parameters for sediment transport are calculated assuming normal depth in the channel.

For numerical sedimentation models to completely simulate the behavior of a stream channel, computations would have to account for all of the basic processes of sedimentation: erosion, entrainment, transportation, deposition, and compaction of both the bed and the streambanks for the complete range of particle sizes found in nature. The state of the art has not yet advanced to such a complete simulation. The computer program used in this study, TABS-1, is a state-of-the-art program for use in mobile bed channels. It is designed to calculate aggradation and degradation of the streambed profile. When applied by experts using good engineering judgement, the TABS-1 program will provide good insight into the behavior of mobile bed channels such as San Timoteo Creek.

Particle sizes from sand to gravel are involved in San Timoteo Creek, which complicates the simulation because particle size controls the fundamental processes in river sediment behavior. The time scale of interest is from a single flood event to the life of the project. The long-term trends can be evaluated from a statistical analysis of the gage records, but a great deal of variation in water and sediment runoff occurs from one storm event to the next because of the stochastic nature of the hydrologic cycle. The approach for bridging these gaps is to formulate (a) a procedure that includes the statistical nature of the boundary conditions - the uncertainty in forecasting

future hydrology and sediment yield is probably more significant than gaps in modeling the physics of the mobile boundary processes so far as the accuracy of results is concerned; and (b) a computer program that emulates the physical processes in the project reach sufficiently well to quantify how the sedimentation processes will respond to changes in the boundary conditions and/or to changes in the project geometry or roughness.

Although the sedimentation processes are complex, procedures for describing most of them have been published. The TABS-1 computer program includes those procedures. Where gaps exist between the available procedures, TABS-1 contains logic that bridges those gaps. In summary, it is state-of- the-art technology for calculating the aggradation and degradation in mobile bed channels, and because it has given reliable results at similar projects, it is expected to give reliable answers to the questions being addressed here.

Channel Geometry

The numerical model extends from station 295+81, at the outlet of the in-channel basins, near the mouth of the San Timoteo canyon, to station 455+01, which is just downstream from the confluence of Yucaipa Creek (see Figure 4). The channel geometry for the simulation was based on field-surveyed cross sections and from topographic mapping dated 1964 (contour interval 5 ft, scale 1:2400) compiled by San Bernardino County. Reach lengths between cross sections are generally greater in a TABS-1 model than in a HEC-2 model. Reach lengths in this model generally range from 436 ft to about 2000 ft in the supply reach and from 34 ft to 490 ft in the sediment basins. Cross-section locations for the supply reach are shown in Figure 4 and for the sediment basins are shown in Figure 5.

Hydrographs

Discharge hydrographs are simulated in the numerical model by a series of steady-state events also referred to as a histograph. The duration of each event is chosen such that changes in bed elevation due to deposition or scour do not significantly change the hydraulic parameters during that event. At relatively high discharges, durations need to be short. And at low discharges, the time interval may be extended.

A 100-year, 3-day balanced flood histograph was used for the simulations for San Timoteo Creek (USAEDLA, 1990). The hydrograph from which the histograph was made is shown on Figure 6. The histograph used has a constant time interval of 30 minutes.

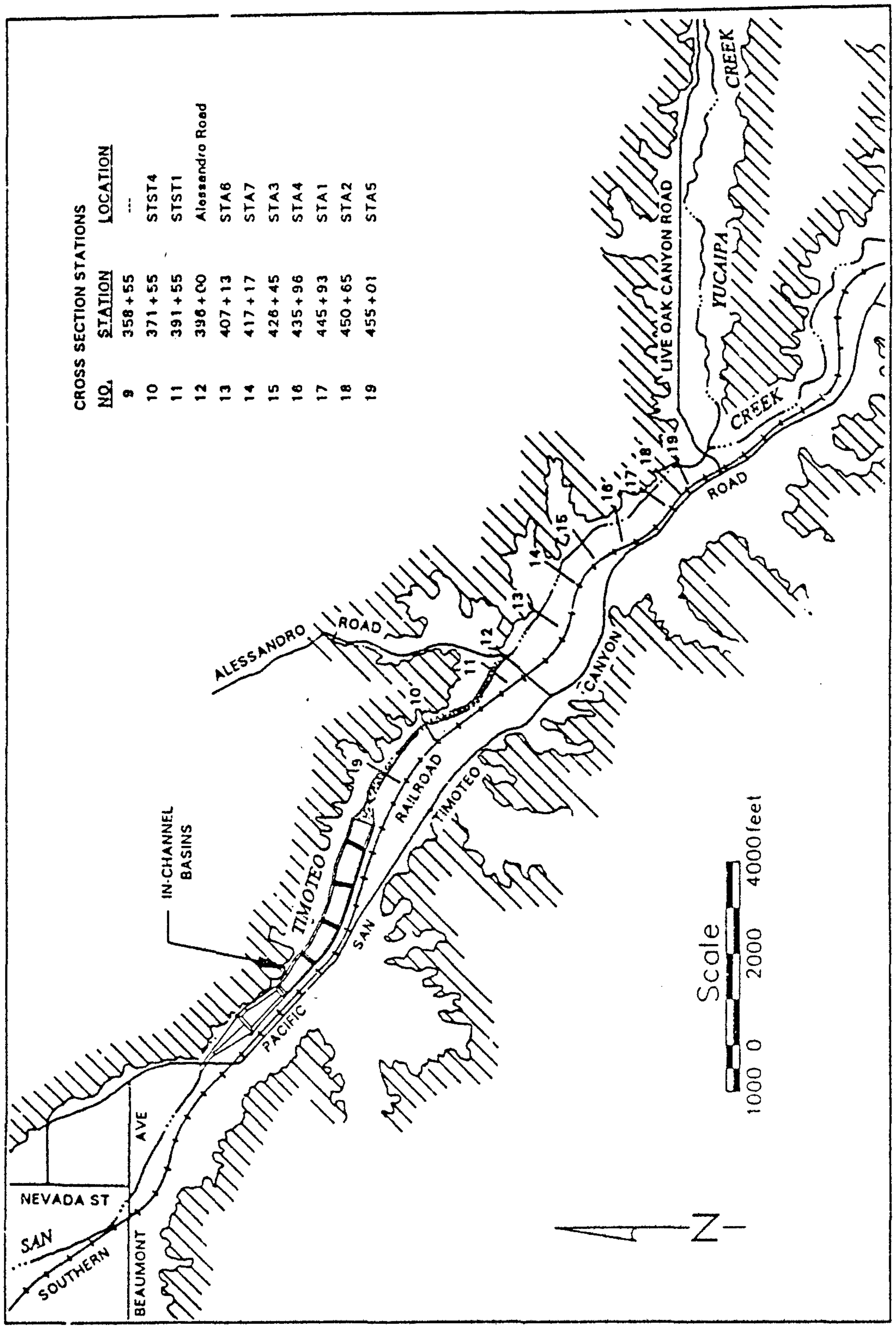
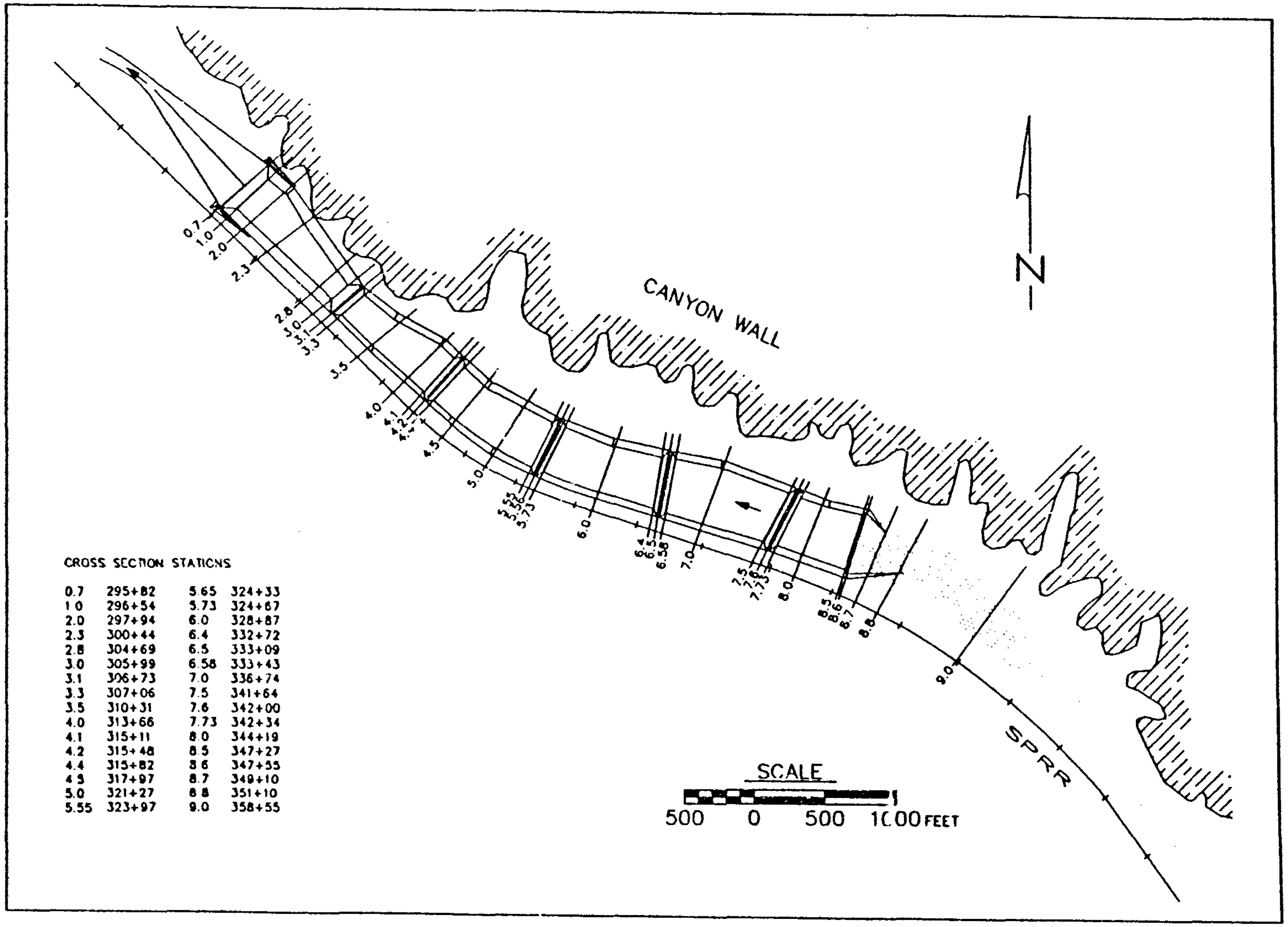


Figure 4. Cross-section locations in supply reach



CROSS SECTION STATIONS

0.7	295+82	5.65	324+33
1.0	296+54	5.73	324+67
2.0	297+94	6.0	328+87
2.3	300+44	6.4	332+72
2.8	304+69	6.5	333+09
3.0	305+99	6.58	333+43
3.1	306+73	7.0	336+74
3.3	307+06	7.5	341+64
3.5	310+31	7.6	342+00
4.0	313+66	7.73	342+34
4.1	315+11	8.0	344+19
4.2	315+48	8.5	347+27
4.4	315+82	8.6	347+55
4.5	317+97	8.7	349+10
5.0	321+27	8.8	351+10
5.55	323+97	9.0	358+55

Figure 5. Cross-section locations in basins

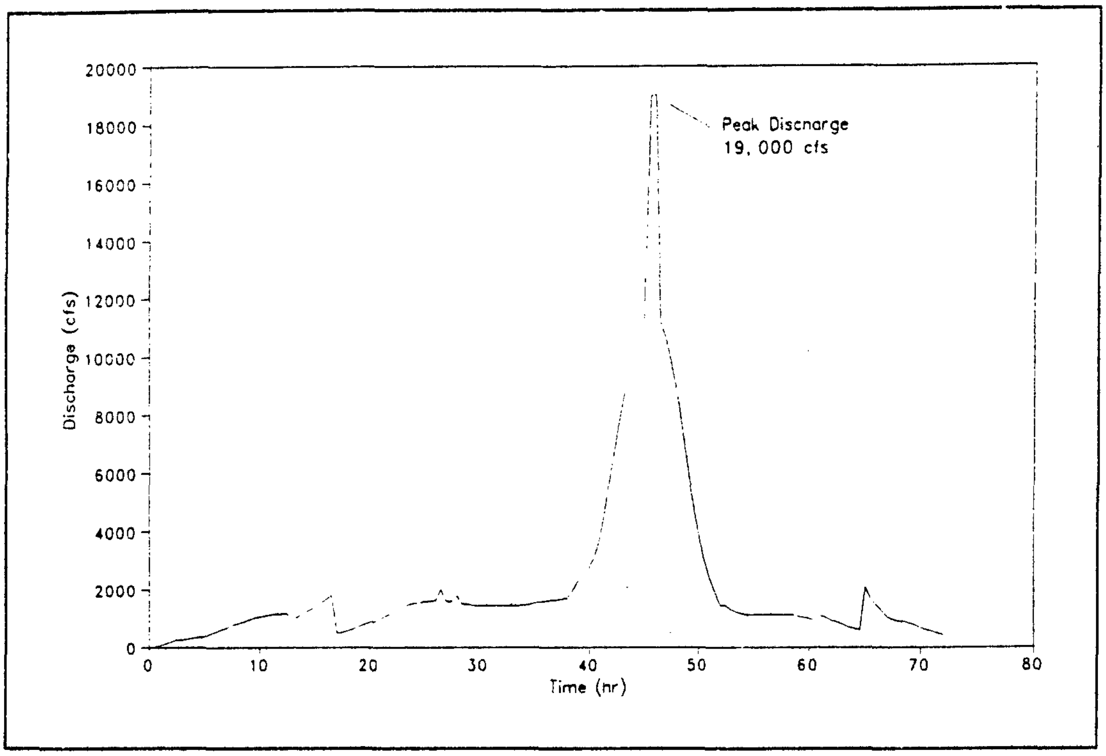


Figure 6. 100-Year hydrograph

Downstream Water Surface Elevation

Starting water surface elevations at the downstream end of the numerical model were based on critical depth. This assumption is valid since the flow regime changes from subcritical to supercritical as flow passes out of the downstream basin into the supercritical channel.

Bed Material

Bed material gradations for the model were based on an extensive bed and bank sampling program that included 101 samples taken at 24 locations throughout the study area. As shown in Figure 1, the sediment samples were generally taken in a representative supply reach upstream from the proposed sediment basins. Sufficient samples were taken to determine if there were any lateral, vertical, or longitudinal variation in the bed. The gradation analyses were based on a standard sieve analysis. Sieve sizes ranged from 3 inches (76.2 mm) to a #270 sieve (0.053 mm); no hydrometer tests were performed. The maximum size of material was about 64 mm with an average D_{50} of about 0.9 mm. An average normalized bed gradation was determined from the bed samples for use in the model (Figure 7).

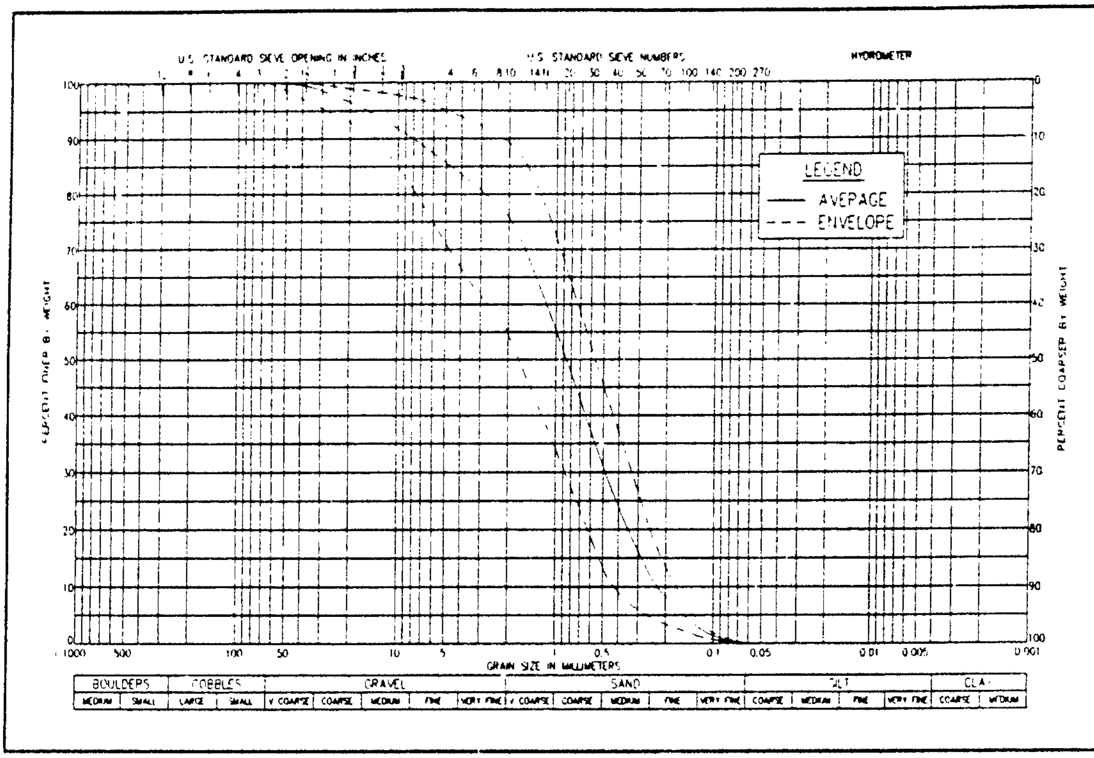


Figure 7. Bed material gradation

In general, bank material usually consists of much finer material than that found in the bed and provides a basis for determining the composition of the wash load. In this study, 32 of the 101 samples were taken of bank material. The maximum size of the bank material was about 64 mm with an average D_{50} of about 0.3 mm. A normalized gradation of bank material is shown on Figure 8. Approximately 18 percent of the material consists of silt.

Channel Roughness

Hydraulic roughness is influenced by grain size or bottom roughness, bank or sidewall roughness, bed form, water depth, changes in channel shape, and changes in flow direction or distribution due to channel bends and confluences. In the one-dimensional numerical model these effects are accounted for by the Manning's roughness coefficient. Acceleration and deceleration of flow are accounted for with expansion and contraction coefficients.

In the sediment supply reach, a Manning's n-value of 0.050 was used based on the conditions existing in the field. Through the in-channel basins, an n-value of 0.030 was used.

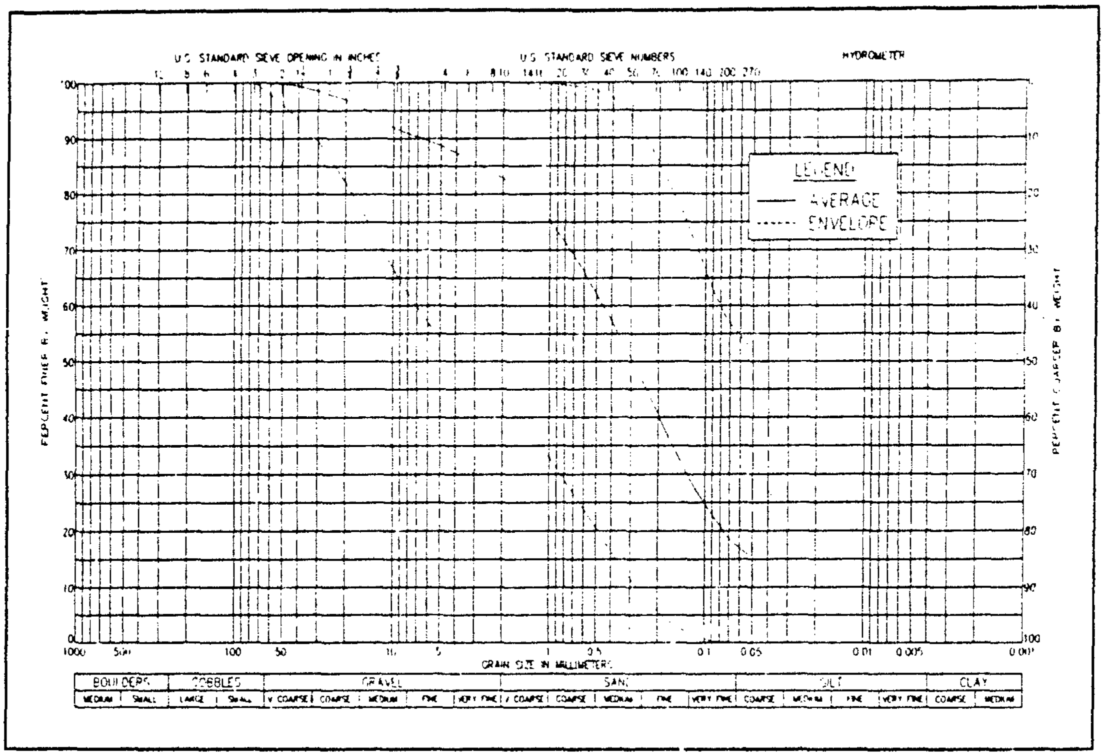


Figure 8. Bank material gradation

Transport Function

Yang's unit stream power function was used for this study. This function is desirable since it has proved applicable for medium to coarse sand-bed streams located in the USAEDLA. Silt transport and deposition is computed by TABS-1 based on an equation developed by Krone (1962) for silt and clay deposition in a recirculating flume.

Additional transport functions were used in the numerical model and tested for sensitivity. These functions included Madden's 1985 modification (Madden 1993) to Laursen's (1958) function and Copeland's modification (Copeland and Thomas 1989) to Laursen's (1958) function. Madden's 1985 modification of Laursen's function adapted Laursen's function for higher Froude numbers and included Toffaleti's river data and Guy, Simons, and Richardson's flume data. Copeland's modification to Laursen's (1958) function included Brownlie's data and incorporated data for transport of gravels in addition to the sand data used to develop the original Laursen function. The Laursen-Copeland function is very sensitive to the fraction of fine and very fine sand present in the bed. This function is best used when measurements of suspended sediment are available to confirm calculated concentrations of fine material.

Sediment Inflow

Measurements of suspended or bed-load sediment do not exist for San Timoteo Creek. Therefore, sand and gravel inflow to the numerical model was calculated assuming equilibrium sediment inflow using average hydraulic parameters in the supply reach and the average normalized bed material gradation (Figure 7). By using the average bed gradation, the computations ignore the effect of armoring and the inflow curves tend to be high especially with a multiple-grain size transport function. Specifically, sediment transport capacities were computed with the sediment transport module of the Hydraulic Design Package for Flood Control Channels (SAM) developed at WES (WES, in preparation). Silt inflow was estimated to be 20 percent of the total sand inflow. This percentage corresponds roughly to the average percentage of silt from bank samples.

Sediment inflow curves are shown in Figure 9 for each transport function. These curves are based on equilibrium transport and include transport of sand, gravel, and 20 percent silt. The inflow curves were adjusted during the sensitivity analysis phase of the study as discussed in Part III, "Study Results." In general, the concentration of silt was varied to determine the sensitivity of silt inflow to the overall trap efficiency of the basins.

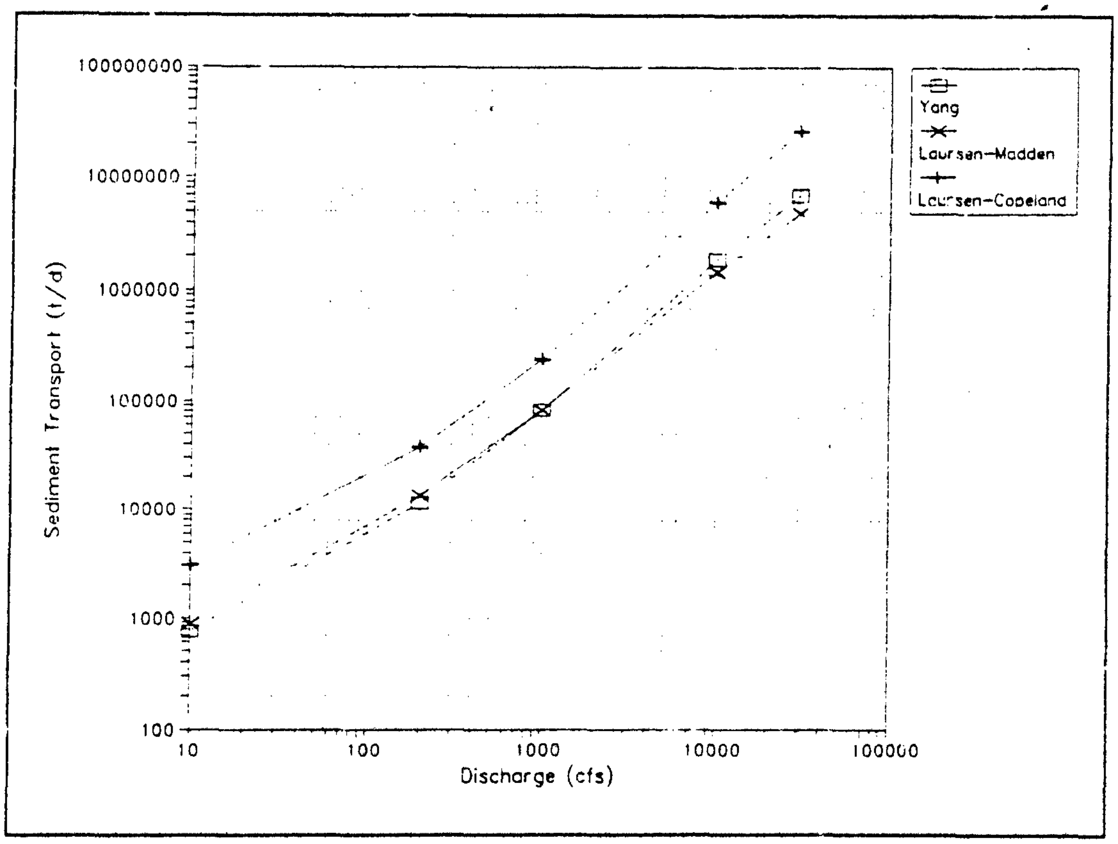


Figure 9. Sediment inflow curves

The curve for the Laursen-Copeland transport function tends to be much higher than the curves for either the Yang or the Laursen-Madden functions. This illustrates the sensitivity of the Laursen-Copeland function to the fraction of fine and very fine sand present in the bed. The Laursen-Copeland function calculates potential transport rates significantly higher than the other two functions for fine and very fine sand. Hence, it is important that the fraction of fine and very fine sand in the bed material gradation be accurate in order for this function to produce reasonable results.

Model Adjustment and Circumstantiation

Adjustment and circumstantiation of the model was not possible due to a lack of prototype data. This situation is typical of ephemeral streams located in the southwest.

3 Study Result

Design Flood

The model was run for the 3-day, 100-year design flood using Yang's transport function. The initial bed elevations were assumed to be at the design levels. Due to the rapid change in cross-section shape at the sediment basins, the numerical integration scheme in the model was set to use "at-station" values for hydraulic parameters. Although the use of at-station values can decrease model stability, the time-steps used for the flood simulations were short enough to prevent model instability problems.

By the peak of the 100-year flood an accumulated total of 340 acre-ft of sediment was delivered to the basins from the supply reach. Approximately 256 acre-ft of sediment was deposited in the basins and an additional 84 acre-ft of sediment by-passed the basins. The by-passed sediment included 61 acre-ft of silt and 23 acre-ft of sand (mostly very fine and fine sand).

At the end of the design flood, a total of 508 acre-ft of sediment was delivered to the basins: 382 acre-ft of sediment was deposited in the basins, and 126 acre-ft of silt and sand (95 acre-ft of silt and 31 acre-ft of sand) had bypassed the basins. The trap efficiency for the total sediment load (i.e. silt, sand, and gravel) was 75.2 percent, and the trap efficiency for sand and gravel was 92.2 percent. Results of this analysis are shown in Figure 10, and a complete summary of the results is tabulated in Table 1.

Of special note is the volume of sediment delivered to the basins from the sediment supply reach. At the end of the flood, a total volume of 499 acre-ft was input at the upstream boundary of the numerical model. This volume is based on the assumption of equilibrium transport using the Yang equation. The model computed a total volume of 508 acre-ft entering the basins which included the net of any aggradation or degradation in the supply reach. Since the difference between these volumes is so small, it appears that the magnitude of the inflowing sediment rating curve is appropriate for this simulation. Additionally, there is a significant difference between the volume calculated using the debris yield method (i.e. 700 acre-ft) and the "transported" volume of 508 acre-ft using the Yang equation.

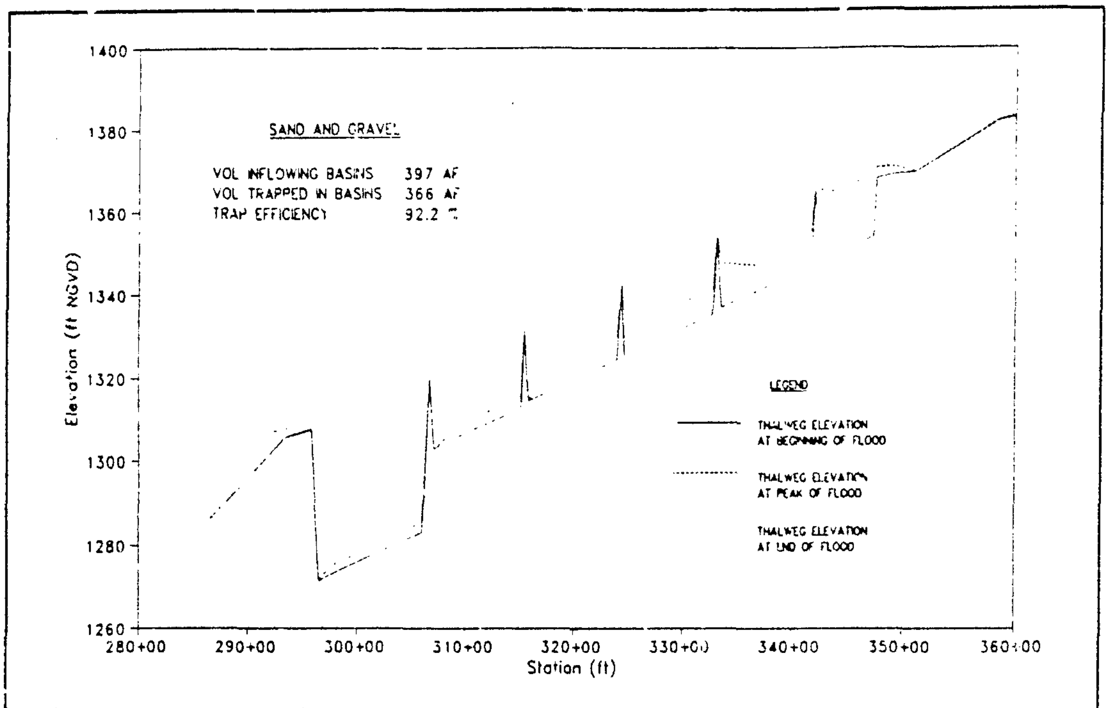


Figure 10. Thalweg profile for Yang

The numerical model was able to simulate the sequential filling of the basins, the variation of deposition rate as each basin filled, the size class distribution of the sediment that passed through the basin, and the slope of the deposited sediments. The one-dimensional model does not account for variation in deposition due to eddies or increased turbulence at the basin inlets.

Sensitivity Studies

It was especially important to determine the model's sensitivity to sediment inflow due to the lack of prototype sediment inflow data. Simulations of the design flood were conducted using two additional sediment transport equations. As expected, different transport equations produced different deposition rates and quantities. Since no suspended sediment data were available for comparison with calculated transport rates, numerical model results were interpreted considering the model's sensitivity to the transport function. Additional sensitivity tests were conducted and included varying the inflow of silt or bed-load material and evaluating possible effects from the imposed initial conditions by accounting for antecedent flows and initial bed gradation. Sensitivity of the model to the downstream water surface elevation or the roughness coefficient were not considered in this analysis.

Table 1 Results for Different Transport Functions					
Transport Function	**Inflowing Supply Reach (AF)**	**Inflowing Basins (AF)**	**Outflowing Basins (AF)**	**Trap Eff. of Basins (%)**	**Vol. Trapped in Basins (AF)**
Total Sediment Load					
Yang	499	508	126	75.2	382
Laursen-Madden	410	397	86	78.4	312
Laursen-Copeland	1590	1675	912	45.6	763
Total Sand Load					
Yang	388	397	31	92.2	366
Laursen-Madden	318	306	11	96.4	295
Laursen-Copeland	1234	1351	590	56.3	761
Very Fine Sand Load					
Yang	175	175	30	82.9	145
Laursen-Madden	97	98	10	89.3	87
Laursen-Copeland	734	731	464	37.0	267
Silt Load					
Yang	111	111	95	14.3	16
Laursen-Madden	92	92	75	18.5	17
Laursen-Copeland	353	353	322	8.8	31

Transport Function

The sensitivity of the model results to the transport function was tested using Madden's (1985) modification to Laursen's function and Copeland's (1989) modification to Laursen's function (Table 1 and Figure 9). Equilibrium transport at the upstream boundary was assumed in the sensitivity tests.

In general, results from the Laursen-Madden function were similar in magnitude to those computed with Yang's. At the end of the design flood, the

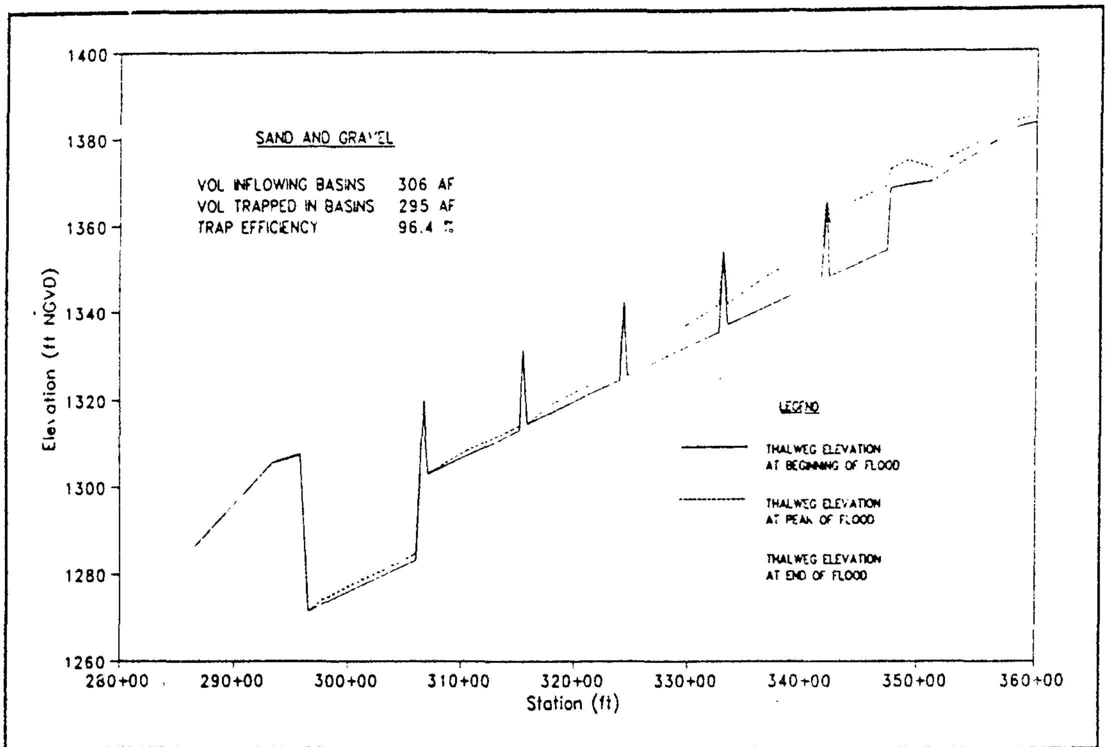


Figure 11. Thalweg profile for Laursen-Madden function

volume of sediment delivered by the supply reach was 397 acre-ft, and the volume of sediment trapped in the basins was 312 acre-ft (Figure 11). The trap efficiency for the total sediment load (i.e. silt, sand, and gravel) was 78.4 percent, and the trap efficiency for sand and gravel was 96.4 percent.

In contrast, results from the Laursen-Copeland function varied significantly compared to those computed with Yang's. At the end of the design flood, the volume of sediment delivered by the supply reach was 1675 acre-ft, and the volume of sediment trapped in the basins was 763 acre-ft (Figure 12). The trap efficiency for the total sediment load was 45.6 percent, and the trap efficiency for sand and gravel was 56.3 percent.

These results demonstrate the importance of selecting a transport function appropriate for the study reach. When sediment inflow to the model is provided from measured prototype data, the HEC-6 model, with its sorting and armoring algorithm, will adjust the bed to accommodate the inflowing load. In this case the choice of transport function is less important. However, when sediment inflow is calculated, assuming equilibrium transport at the upstream boundary, variability in calculated results may be significant. Greater variability can be expected in multiple-grain size functions, such as derivatives of the Laursen equation. For this reason, results calculated using the Yang equation are considered more reliable. Results calculated using the Laursen equations demonstrate the range of uncertainty.

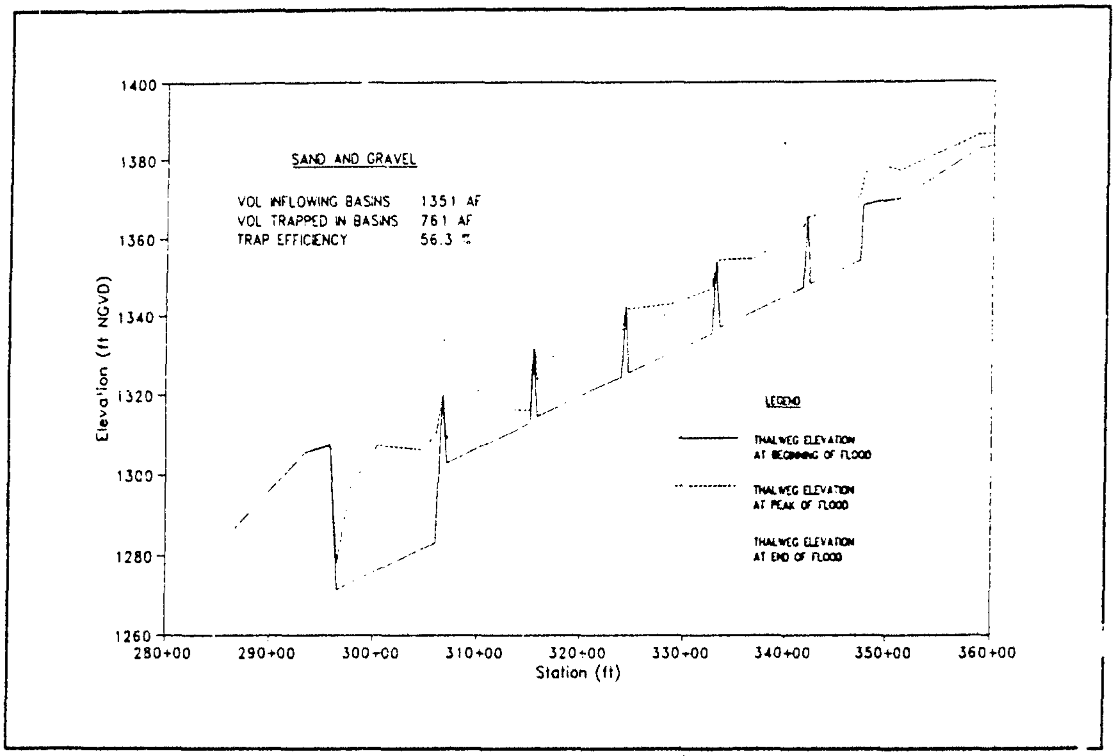


Figure 12. Thalweg profile for Laursen-Copeland

Concentration of Fines

The sensitivity of the proposed design to sediment inflow was tested with the design flood. These simulations included: 1) the Yang and Laursen-Copeland functions with bed-material inflow only, no silt; and 2) the Laursen-Madden function with the inflow of silt increased such that a total of 700 acre-ft (i.e. the 100-year debris yield estimate) of sediment would inflow the supply reach during the design flood. Results are tabulated in Table 2.

Without Silt. For Yang's function, the volume of sediment delivered by the supply reach, at the end of the design flood, was 384 acre-ft, and the volume of sediment trapped in the basins was 368 acre-ft (Figure 13). The trap efficiency for the sediment load (i.e. sand, and gravel only, no silt) was 96.0 percent. For the Laursen-Copeland function, the volume of sediment delivered by the supply reach, at the end of the design flood, was 1264 acre-ft, and the volume of sediment trapped in the basins was 786 acre-ft (Figure 14). The trap efficiency for the sediment load (no silt) was 62.2 percent.

These sensitivity tests indicate that sand and gravel inflow from the supply reach decreases by three to six percent and less sand will by-pass the basins compared to tests with silt. Additionally, the trap efficiency increases by roughly four to six percent. Based on these results, the absence of silt does not significantly affect the performance of the basins.

Table 2
Results for Sediment Inflow Sensitivity Tests

Transport Function	Inflowing Supply Reach (AF)	Inflowing Basins (AF)	Outflowing Basins (AF)	Trap Eff. of Basins (%)	Vol. Trapped in Basins (AF)
Total Sediment Load					
Yang [1]	388	384	16	96.0	368
Laursen-Copeland [2]	1234	1264	477	62.2	786
Laursen-Madden [2]	700	746	321	56.9	425
Laursen-Madden [3]	381	355	7	98.2	348
Total Sand Load					
Yang [1]	388	384	16	96.0	368
Laursen-Copeland [1]	1234	1264	477	62.2	786
Laursen-Madden [2]	314	359	11	96.9	348
Laursen-Madden [3]	381	355	7	98.2	348
Very Fine Sand Load					
Yang [1]	175	175	15	91.2	159
Laursen-Copeland [1]	734	731	398	45.6	334
Laursen-Madden [2]	95	99	11	88.9	88
Laursen-Madden [3]	124	122	6	94.8	116
Silt Load					
Yang [1]	--	--	--	--	--
Laursen-Copeland [1]	--	--	--	--	--
Laursen-Madden [2]	287	387	310	19.8	76
Laursen-Madden [3]	--	--	--	--	--

Notes: [1] Numerical model run without silt inflow for sensitivity test.
[2] Inflow load of silt increased so that a total volume of 700 acre-feet of sediment is delivered to the supply reach.
[3] The bed-material gradation used for this test is one standard deviation finer than the average normalized gradation and has a D_{50} of about 0.65 mm. Silt is not included in the inflow.

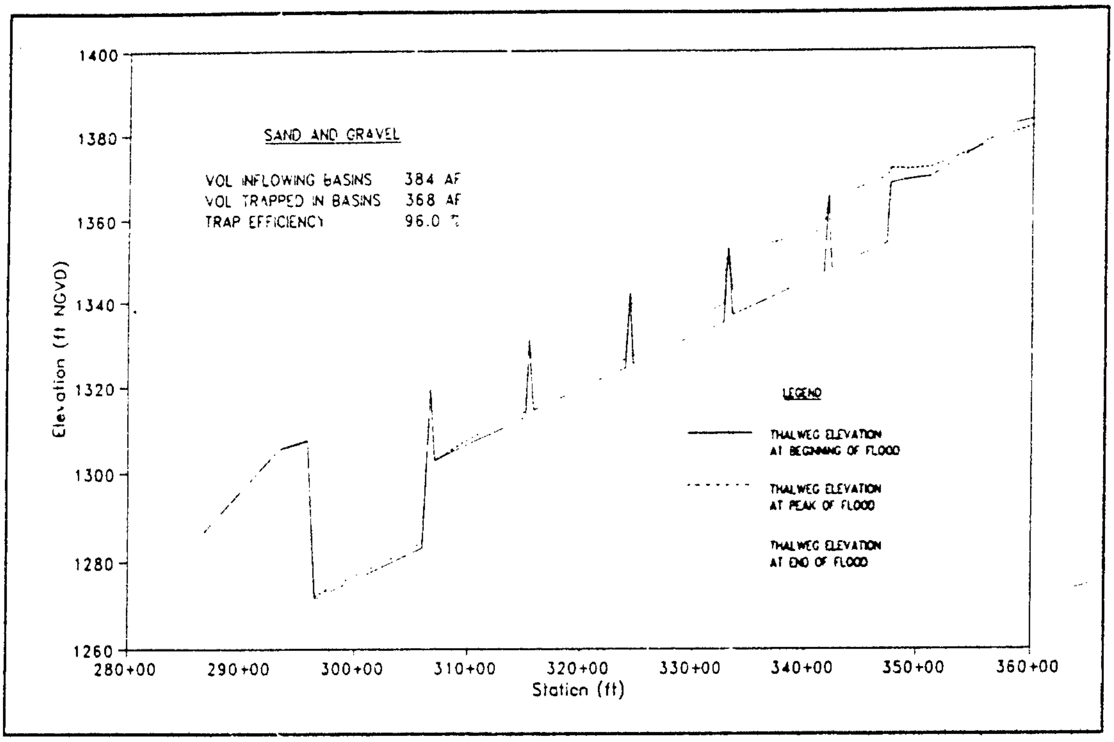


Figure 13. Yang's function without silt

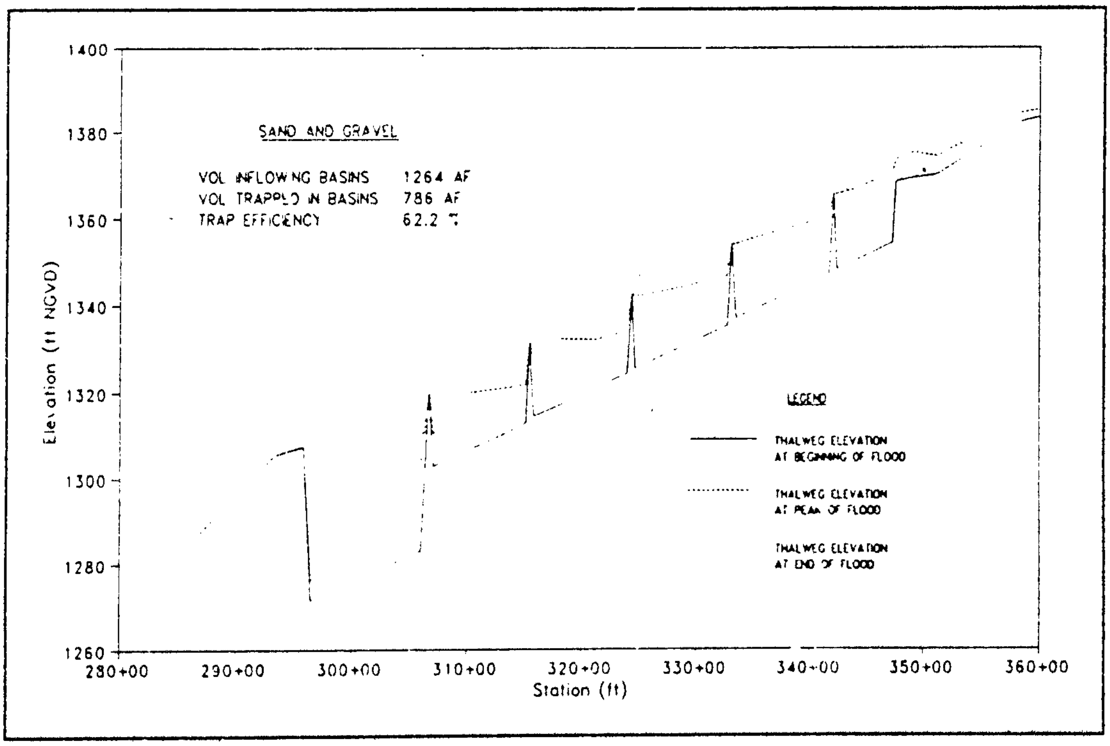


Figure 14. Laursen-Copeland function without silt

Silt Inflow Increased. In this test the percentage of silt was increased from 20 percent to approximately 84 percent (of the sand and gravel load) so that the total volume of sediment delivered to the supply reach, based on the inflow sediment curve and the 100-year histograph, would equal 700 acre-ft. At the end of the design flood, the volume of sediment delivered to the basins from the supply reach was 746 acre-ft, and the volume of sediment trapped in the basins was 425 acre-ft (Figure 15). The 746 acre-ft delivered to the basins included 387 acre-ft of silt and 359 acre-ft of sand and gravel. With a silt inflow of 20 percent, the Laursen-Madden function delivered 306 acre-ft of sand and gravel to the basins. The increase in sand and gravel volume (i.e. 45 acre-ft) is due to the increase in the concentration of silt which increased the potential transport of the bed-material load through the supply reach. The additional 45 acre-ft of sediment was generated by significant degradation of the supply reach. The trap efficiency for this sediment inflow scenario was 56.9 percent.

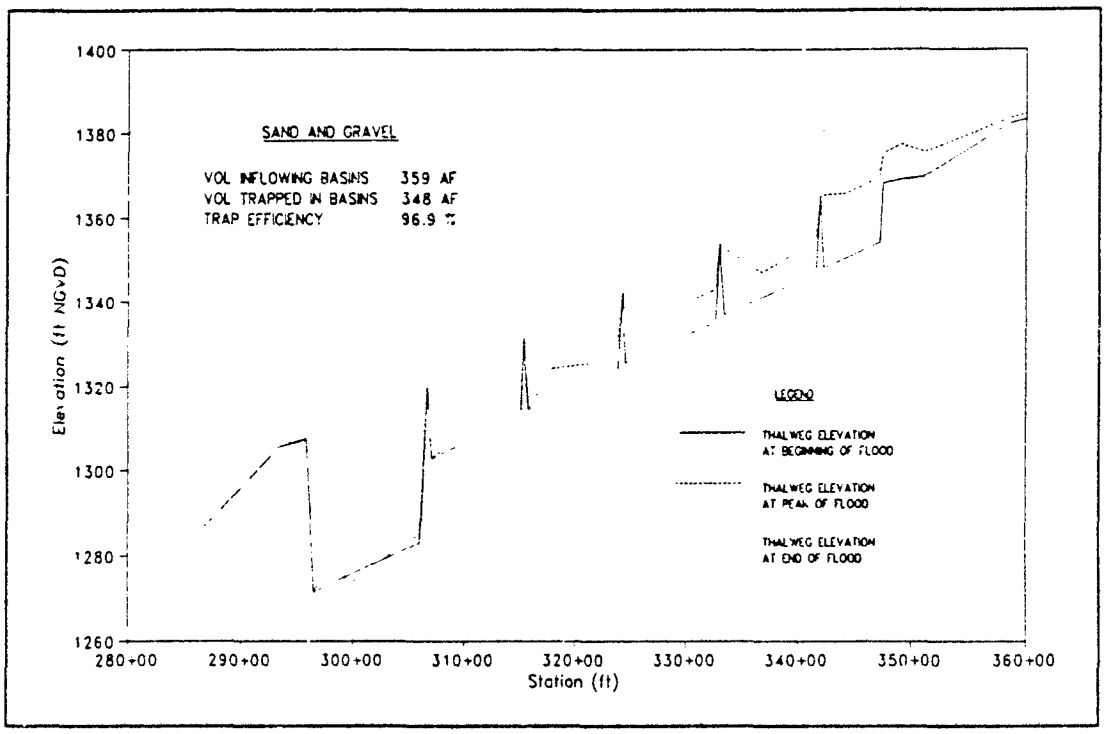


Figure 15. Laursen-Madden function with silt inflow increased

The increase in sand and gravel entering the basins (45 acre-ft) is due to the increased potential transport of the bed-material load due to increased viscosity resulting from the increased concentration of fines. The additional 45 acre-ft of sediment was generated by degradation of the supply reach. The trap efficiency for sand and gravel was not affected by the addition of silt (i.e. 96.4 percent with 20 percent silt versus 96.9 percent with 84 percent silt) and indicates that the performance of the basins is not significantly affected by the concentration of inflowing silt.

Initial Bed Gradation

The sensitivity of the proposed design to the gradation of the inflowing bed-material load during the design flood was tested using the Laursen-Madden (1985) function with the inflow sediment curve computed (by SAM) with a bed material gradation one standard deviation finer than the average normalized bed material gradation. The bed-material gradation used for this test is shown in Figure 16. The material is one standard deviation finer than the average normalized gradation and has a D_{50} of about 0.65 mm. At the end of the design flood, the Laursen-Madden function transported 355 acre-ft of sediment from the supply reach to the basins. The volume of sediment trapped in the basins was 348 acre-ft (Figure 17). The trap efficiency for the sediment load (no silt) was 98.2 percent.

When the gradation of the inflow load is one standard deviation finer than the average bed gradation, the volume of sand and gravel inflowing the basins increases as expected. However, with this scenario, the trap efficiency increases as well as the volume of material trapped in the basins. Although the bed-load material is finer, more material is trapped by the basins in this test than the test with the average gradation and silt. When silt is present, it tends to "displace" volume which is otherwise filled by sand and gravel.

Antecedent Flow

The effect of increasing the antecedent flow was tested by running two consecutive 100-year floods. The transport functions used in these tests included the Yang and Laursen-Madden functions. Results are tabulated in Table 3. For Yang's function, the volume of sediment delivered by the supply reach, at the end of the design flood, was 1015 acre-ft, and the volume of sediment trapped in the basins was 679 acre-ft (Figure 18). The trap efficiency for the total sediment load was 66.9 percent. For the Laursen-Madden function, the volume of sediment delivered by the supply reach, at the end of the design flood, was 788 acre-ft, and the volume of sediment trapped in the basins was 584 acre-ft (Figure 19). The trap efficiency for the total sediment load was 74.1 percent.

As expected, when the numerical model was run with two consecutive 100-year floods, the total volume of sand and gravel inflowing the basins doubles, and the volume of sediment by-passing the basins increases. By the end of the second 100-year flood, the test with Yang's function indicates that 679 acre-ft would be trapped in the basins, and the test with the Laursen-Madden function indicates that 584 acre-ft would be trapped. In both cases, additional storage volume exists at the end of the second 100-year flood since the basins have a volume of 765 acre-ft when empty. Additionally, when compared to the single 100-year flood, the trap efficiency for sand and gravel decreases, as expected, from 92.2 and 96.4 percent to 82.9 and 92.3 percent, for the Yang and Laursen-Madden functions, respectively.

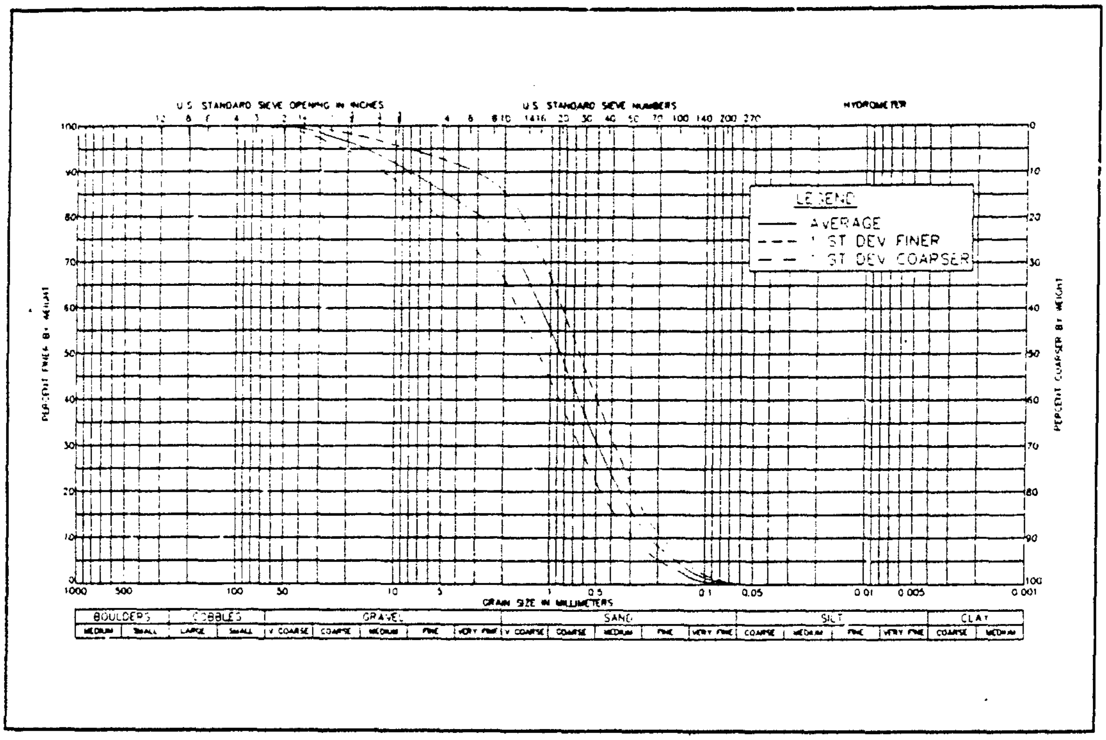


Figure 16. Gradation of material one standard deviation finer

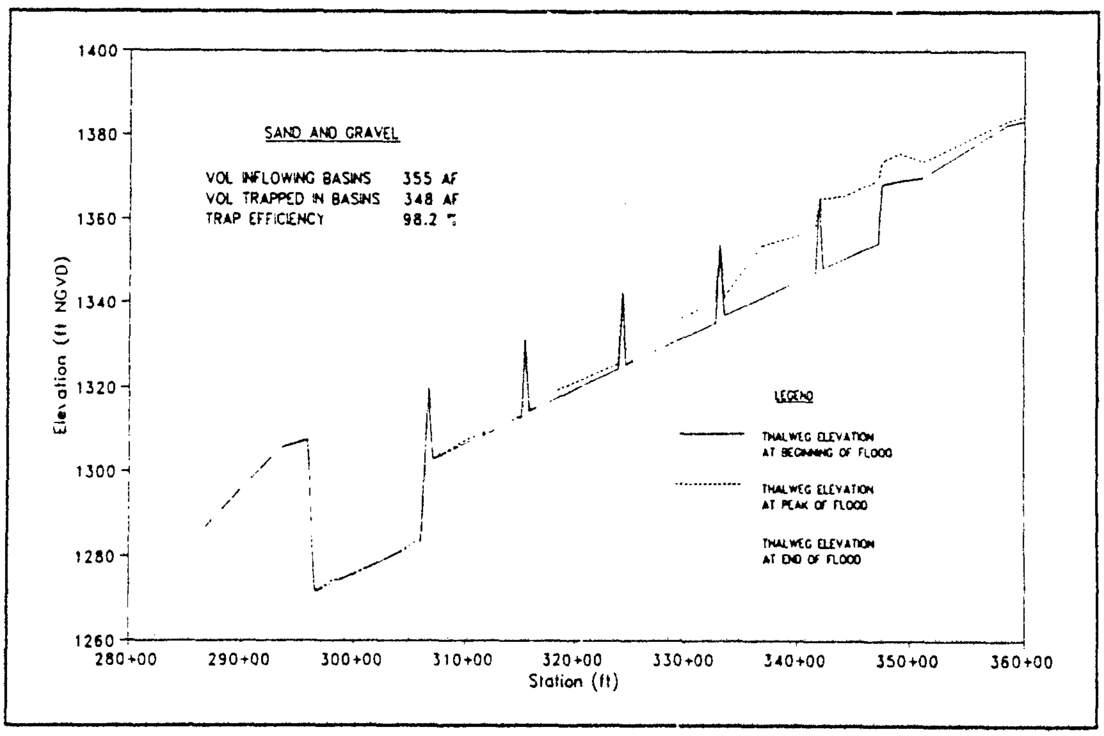


Figure 17. Laursen-Madden function with material one σ finer

Table 3 Results for Antecedent Flow Sensitivity Tests					
Transport Function	**Inflowing Supply Reach (AF)**	**Inflowing Basins (AF)**	**Outflowing Basins (AF)**	**Trap Eff. of Basins (%)**	**Vol. Trapped in Basins (AF)**
Total Sediment Load					
Yang	998	1015	336	66.9	679
Laursen-Madden	820	788	204	74.1	584
Total Sand Load					
Yang	776	793	136	82.9	657
Laursen-Madden	636	605	47	92.3	558
Very Fine Sand Load					
Yang	350	349	117	66.6	233
Laursen-Madden	194	194	38	80.6	157
Silt Load					
Yang	222	222	200	9.9	22
Laursen-Madden	184	184	158	14.2	26

Performance of In-Channel Basins

Overall, results from the sensitivity studies indicate that the in-channel sediment basins will function adequately. As expected, application of different transport functions resulted in computed trap efficiencies for sand and gravel ranging from 56.3 to 96.4 percent when silt is included in the model. When silt is omitted from the computations, trap efficiencies for sand and gravel ranged from 62.2 to 98.2 percent. In either case, the basins trapped most of the coarse, bed-load material and passed the fine sand and silt on to the concrete channel.

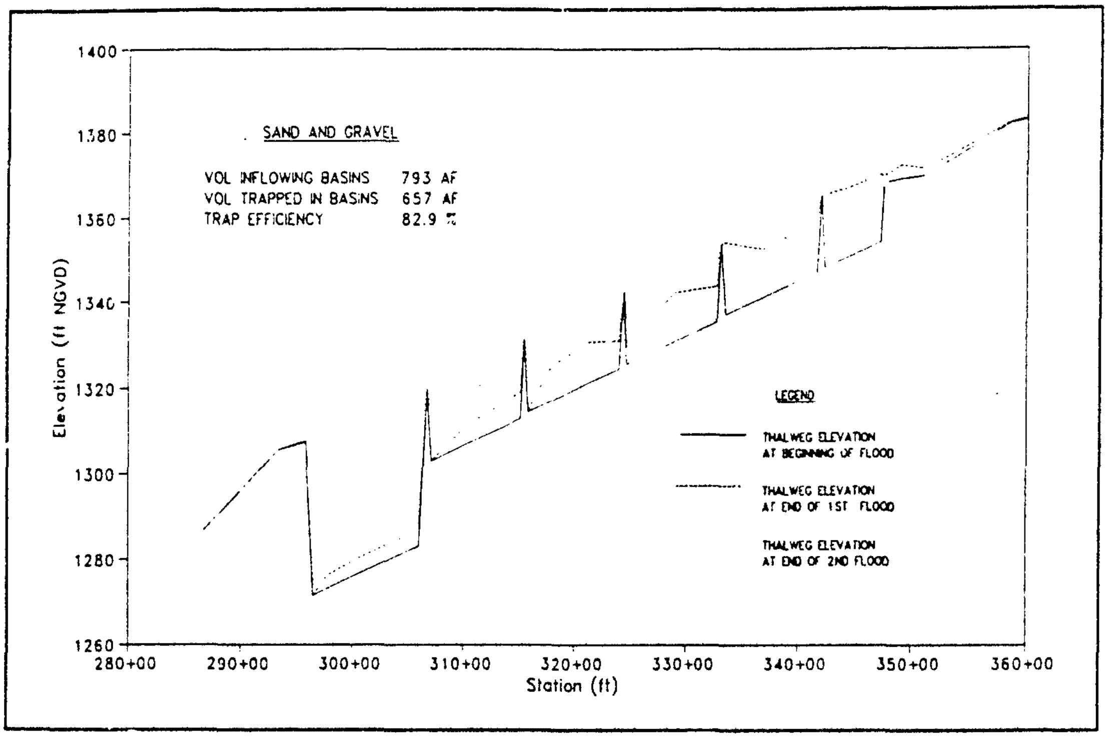


Figure 18. Yang's function for two 100-year floods

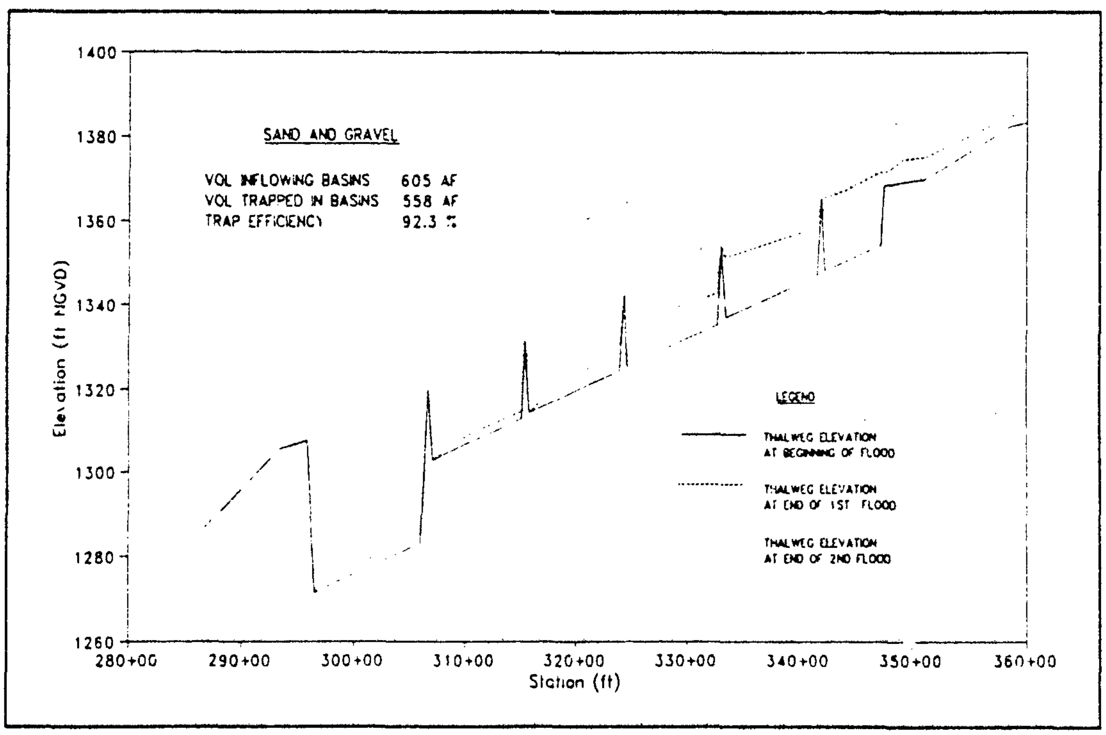


Figure 19. Laursen-Madden function for two 100-year floods

4 Conclusions and Recommendations

Conclusions

Numerical modeling, using a research version of the one-dimensional sediment transport model TABS-1 (HEC-6), was performed by the USAEDLA and WES to ensure that the in channel debris basins would function as designed during a design flood. The numerical model was able to simulate the sequential filling of the basins, the variation of deposition rate as each basin filled, the size class distribution of the sediment that passed through the basin, and the slope of the deposited sediments. The one-dimensional model does not account for variation in deposition due to eddies or increased turbulence at the basin inlets.

Based on Yang's transport function, the volume of sediment delivered to the in-channel basins during the 100-year flood is about 508 acre-ft. Approximately 382 acre-ft of sediment will be deposited in the basins, and 126 acre-ft of silt and fine sand will by-pass the basins. The total calculated trap efficiency of the six sediment basins for the 100-year histograph was 75.2 percent. Trap efficiency for sand and gravel was 92.2 percent and for silts was 14.3 percent. 97 percent of the sand passing through the basins was smaller than 0.125 mm. Material passing through the basins will be easily transported in the high-energy concrete channel.

Results of this analysis concluded that the in-channel basins performed satisfactorily for a relatively wide range of conditions. A series of sensitivity tests were conducted to verify the design given the lack of measured or prototype data. For a case like this, it is important that several techniques be incorporated into the overall analysis to minimize uncertainty and risks. This analysis included results based on the USAEDLA debris yield method and a sediment transport-based TABS-1 numerical model study.

Recommendations

The numerical model for this analysis was conducted with basins that had a total storage volume of 765 acre-ft. However, upon running the numerical model, it was determined that the stream was transport limited. That is, based on Yang's transport function, a total volume of 508 acre-ft would be delivered to the basins; whereas, the estimation of debris yield is 700 acre-ft. It is recommended that future study include optimizing the size of the in-channel sediment basins and testing for reliability.

A sediment gaging station and sampling program should be developed and implemented in order to reduce uncertainty and risks in the design. Prior to construction, sediment sampling would provide insight to the reasonableness of the sediment transport rates and volumes discussed herein. After construction, detailed operation and maintenance records should be maintained regarding the material removed from the basins and should include the volume, size (i.e. gradation information if possible), and type of material (i.e. organic versus inorganic). This information would provide the basis for determining the effectiveness of the prototype basins.

The methodology for in-channel sedimentation basin design applied to the San Timoteo Creek flood control project can be generalized for use in similar projects. The approach uses the TABS-1 (HEC-6) one-dimensional sediment model to determine deposition patterns for alternative designs. Model adjustment and circumstantiation are required with special attention to sediment inflow. Sensitivity studies address uncertainties in the design's approach.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1994	Final report

4. TITLE AND SUBTITLE
San Timoteo Creek, California, Sedimentation Study; Numerical Model Investigation of In-Channel Sediment Basins

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Los Angeles
P.O. Box 2711, Los Angeles, CA 90053-2325

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper
HL-94-6

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers,
Washington, DC 20314-1000;
U.S. Army Engineer Waterways Experiment Station,
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The U.S. Army Engineer District, Los Angeles, proposed channel improvements to the San Timoteo Creek, San Bernardino County, California. Because the watershed involved has the potential to supply a large amount of sediment during a storm event, debris basins were required to assure that the proposed channel would function as designed. The traditional dam-style debris basin design was aesthetically unacceptable to local residents, and the local flood control agency raised concerns about dam safety. Thus, a series of six in-channel sediment basins was designed. The series of basins was designed to fill sequentially with the total sediment storage capacity sufficient for expected needs. The conceptual design of the basins was unproven so detailed analyses were required to verify the design. This was accomplished using the numerical models TABS1 (HEC-6) and SAM. TABS1 was able to simulate sequential filling of the basins, the variation of deposition rate as each basin filled, the size class distribution of the sediment that passed through the basin, and the slope of the deposited sediments. A series of sensitivity tests were conducted to verify the design given the lack of measured prototype data. Overall results concluded that the in-channel basins performed satisfactorily for a relatively wide range of conditions. This methodology for sedimentation design is unique and provides an approach that may be generalized to other flood control channel projects.

14. SUBJECT TERMS
Debris basins
In-channel sediment basins
SAM
SanTimoteo Creek
TABS1 (HEC-6)

15. NUMBER OF PAGES
36

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		